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The Environment of a Herring Fishery

By JOHN H. STEELE, B.Sc.

EDINBURGH: HER MAJESTY'S STATIONERY OFFICE

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The Environment of a Herring Fishery

By JOHN H. STEELE, B.Sc.
Marine Laboratory, Aberdeen–April, 1961

EDINBURGH: HER MAJESTY'S STATIONERY OFFICE
1961

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The Environment of a Herring Fishery

INTRODUCTION

Pelagic fish often undertake long migrations, of which the main directions are very similar from ar to year. The environmental factors which stimulate the fish during these migrations, and the means which the fish detect them, are still largely unknown, though it is often possible to see large scale rrelations between such migrations and, say, temperature and salinity contours, and one can give eological explanations of these journeys in terms of feeding, spawning and so on.

For example, Cushing (1955) gives the possible migration route in the North Sea of the adult tumn-spawning herring of the "Banks" stock (Fig. 1). A similar picture is also given by Parrish and aig (1957). Some relevant environmental features are given in Fig. 2a and b. These are taken from idies of the hydrography (Steele, 1957) and the primary production (Steele, 1958) in the northern orth Sea. It can be seen that there are correspondences between the current system, the times of high imary production and the herring movements. From February to April the fish appear to lie near the ge of the Baltic outflow which, owing to the stability of the surface layer of fresher water, is the only oductive region in early spring. After this they spread westwards at the time when the spring outburst comes general in the rest of the North Sea. During the summer, when production is highest to the st of the area, the herring appear to gather here and move south in the general current direction. stly, after spawning, their probable migration towards the Skagerrak corresponds to the time of the ain water movements in this direction (Tait, 1937).

Beyond such general similarities, the problem is to demonstrate more detailed relations. Henderson Hardy *et al*, 1936) showed that over the area of the summer fishery there was a general but rather eak correlation between herring catches and *Calanus* abundance as sampled by Hardy's plankton dicator. Glover (1957) has suggested that, in the same area, the general north-south distribution of rring is related to the type of plankton communities. The difficulties in obtaining more exact relations this area may arise from the fact that the environmental changes, both hydrographic and planktonic, not usually show very marked or very regular patterns. From this point of view the area is not par-ularly suitable for detailed environmental studies.

In contrast to the irregular and unpredictable changes occurring in the western part of the northern orth Sea during summer, it had been observed on general surveys (Steele, 1958) that there seemed to regular and very marked changes at the western edge of the Baltic outflow in the spring. These changes ere thought to have the following typical features on an east-west section across the Norwegian Deeps ig. 3). About the end of March, the Baltic outflow with low salinity and temperature forms a stable yer sharply bounded on the west by a homogeneous mass (Fig. 3a). It is probably the strong vertical ixing in this mass which prevents the fresh water from moving westward (Steele, 1957). However, in riods of warm, calm weather, or of easterly winds, there may be some mixing at the edge, particularly ter in the season (Fig. 3b). Later in the spring the water to the west will become warmer near the rface, forming a stable layer which will then be able to mix with the Baltic water producing the nerally westward movement shown in Fig. 3c. These changes in stability control the plant production shown by the shading in Fig. 2. Initially, production starts in the stable Baltic water but, as the nutrients e depleted in this layer, production can only occur at its edge when there is inter-mixing. Finally this yer is left unproductive when plant growth becomes general over the rest of the North Sea. The supply zooplankton dependent on the plant food should follow the same pattern.

The pattern of the fishery (Fig. 1) shows that the herring are in roughly this area during March id April and it seemed possible that they might be lying close to the edge of the Baltic water. The

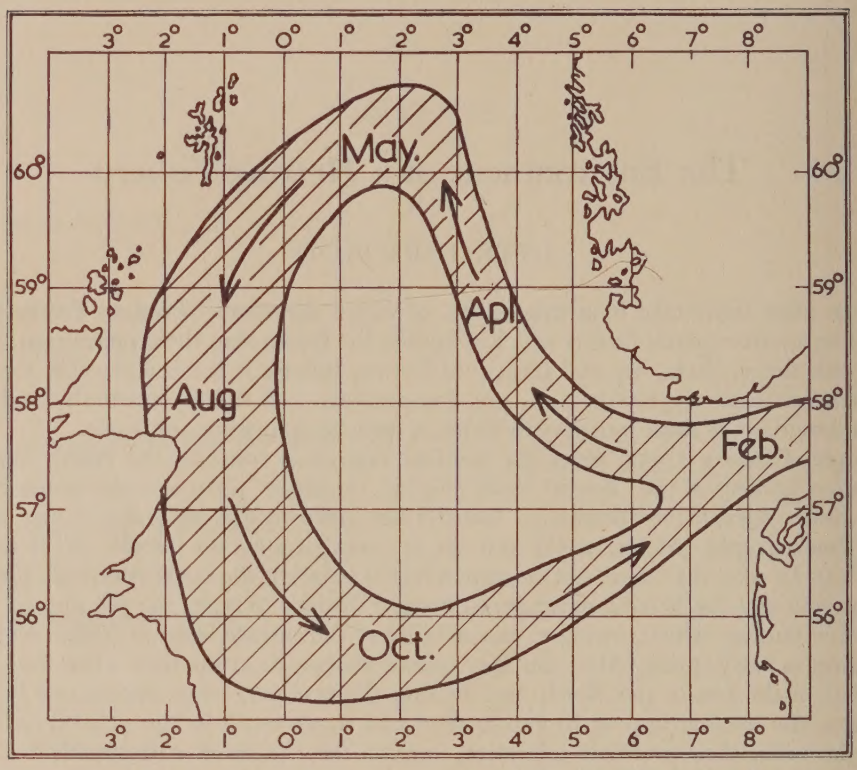

Fig. 1. The hypothetical migration cycle of the "Bank" stock of North Sea herring according to Cushing (1955).

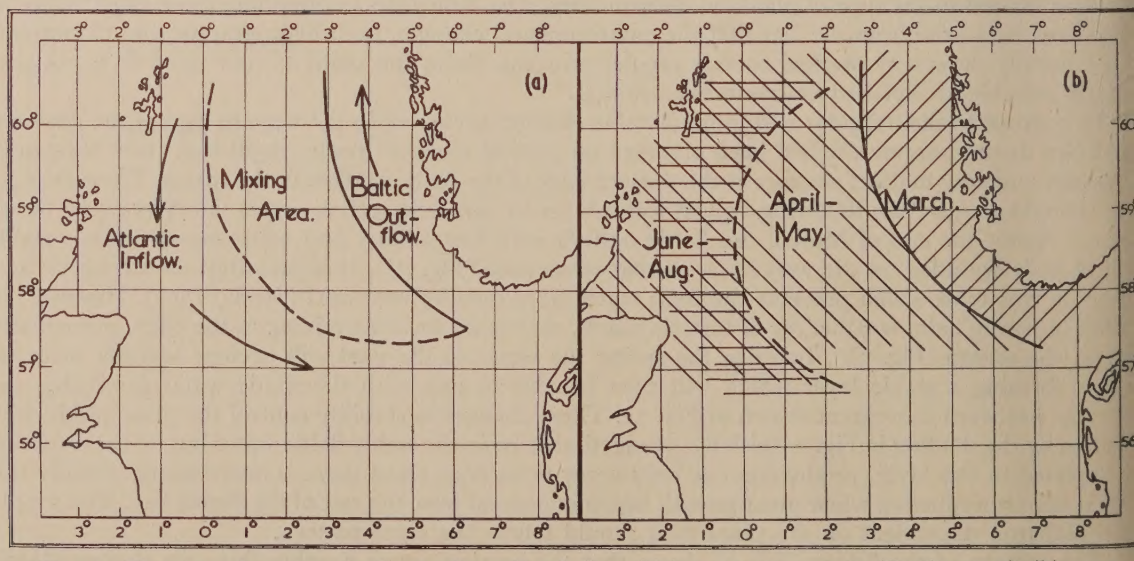

Fig. 2. The general patterns in the northern North Sea of (a) water movements (Steele, 1957), (b) areas of high production (Steele, 1958).

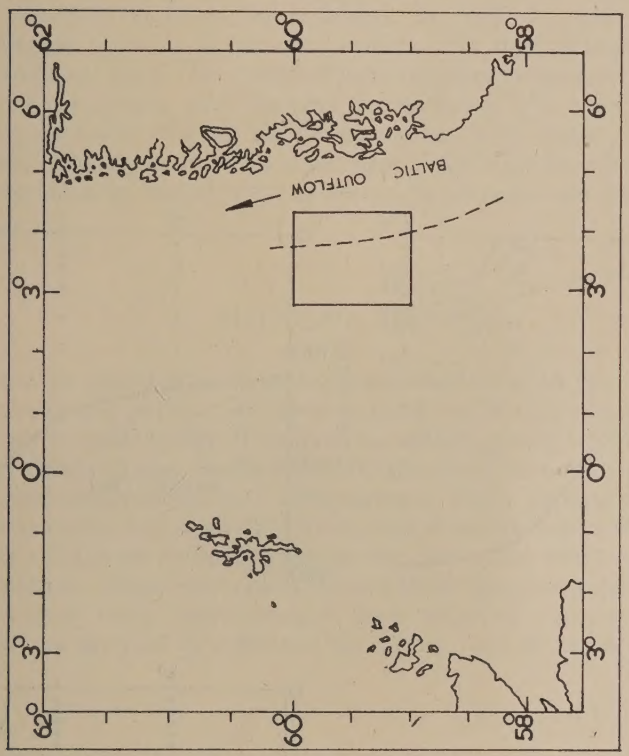

Fig. 4. The approximate area in which all the surveys, 1957-60, were made.

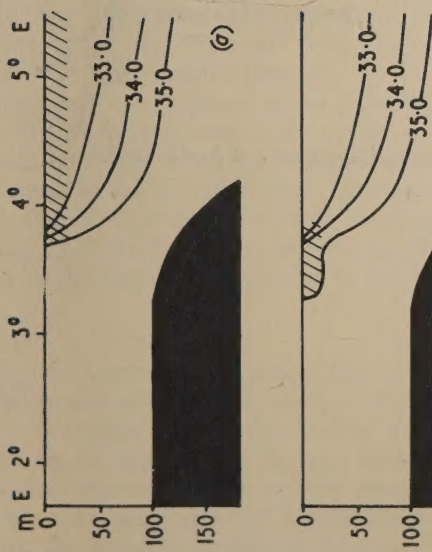

Fig. 3. Idealised sections across the Norwegian Deeps showing (a) sharp boundary to the edge of the Baltic outflow in March, (b) slight mixing as vernal heating begins in early April, (c) extensive mixing after the thermocline is established to the west. The shaded areas indicate regions with high plant production.

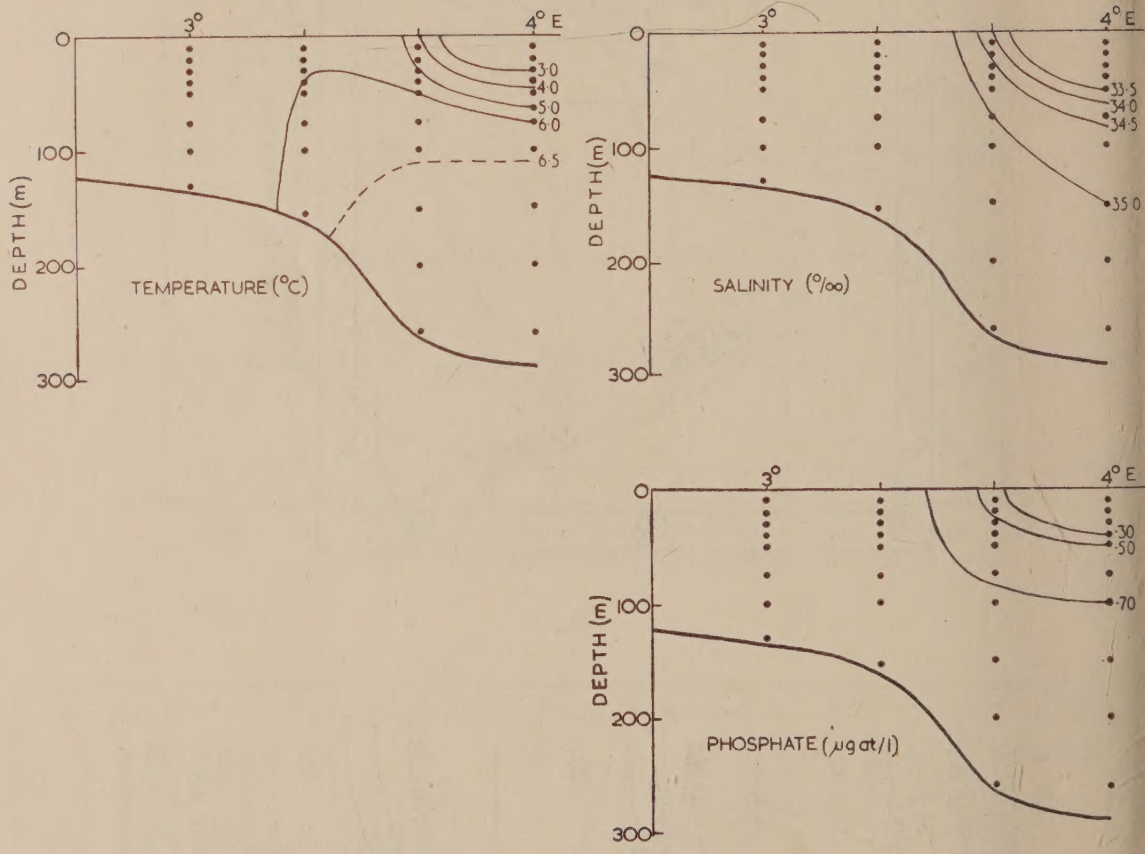

Fig. 5. Conditions on a section along 59°00′N during 4-8 April, 1958.

llowing tentative explanation is offered. Firstly the fish are attracted to the Baltic water to feed, as it is e only productive region in the North Sea in March. Secondly they tend to avoid the colder and less line waters of this outflow: there is experimental evidence that herring stop feeding below 4°C (Johnson, 39; Blaxter and Holliday, 1958). The effect of these opposing tendencies would be to concentrate the rring on the edge of the stream, until the edge breaks down. Thereafter the westward spread of the h (Fig. 1) might be associated with the similar movement of the water.

For these reasons, detailed surveys of a small part of the edge have been carried out from 1957 to 60 at the time when the edge begins to break down. All of them were roughly in the rectangle shown Fig. 4.

SURVEYS 1957-1960

The data will not be presented in a strictly chronological order but in a sequence which shows, stly, examples of the simple pattern, and then some of the complications. The station positions were a grid approximately 10 miles square. Temperature, salinity, phosphate and chlorophyll were sampled various depths but always at 10m, which is used for the charts unless otherwise stated. Surface temperure was also recorded continuously on a thermograph, which permits sudden temperature changes be plotted more accurately than from the station data alone. A Kelvin Hughes MS24G echo sounder as run continuously on a scale 0-180 fathoms so that the whole water column was scanned. All the finite traces were plotted. These were nearly always of the type associated with herring and on nearly ery occasion when good traces were obtained there occurred a concentration of boats fishing for rring. Zooplankton was sampled by a Hensen net during 1957-58 and by a high speed sampler (Gulf I) during 1959-60.

PRIL, 1958

In 1958 the first survey showed conditions before there was any appreciable breakdown at the edge ig. 5). The Baltic water was very cold and the thermograph indicated an extremely sharp edge, nerally with a drop of about 2°C in one to two miles as shown in Fig. 6a. Although the station spacing nnot demonstrate such sudden changes in the other variables, it is apparent from Fig. 6b that the ostulated features of the primary productivity were also found, as shown by the lower phosphate and ry high chlorophyll values to the east. The chart of the distribution of traces in Fig. 6a also gives the osition of the temperature edge and shows that nearly all the traces lie close to this edge. The two aces to the east of the edge were both at depths between 70 and 80 metres and so outside the main art of the cold water wedge (Fig. 5).

On a second survey about a week later (Fig. 6) the edge had partially broken down and as an dication of this the positions of the upper and lower temperatures of the previous sudden change are ven. There was a similar spread in the salinity and phosphate values, and the highest chlorophyll values ow lay roughly in the area of mixing. The correspondence between this breakdown and the herring traces obvious; the fish had started to move westwards following approximately the region of mixing.

Thus in 1958 the first survey showed conditions very like the idealised picture given in Fig. 3a, and ie second survey followed the pattern of the initial stages of the breakdown of the edge (Fig. 3b).

PRIL, 1957

In 1957 the surveys were made later in April than in 1958 and the westerly spread had already arted. The section at 59°20′N across the Deeps (Fig. 7) shows this but also shows a pronounced deepening f the layer of fresher water between 3°00′ and 3°20′E. This probably gives the original position of the dge which can be indicated by the 50m contour of the 35·00‰ isohaline (Fig. 8a). It is known that the esterly spread can occur very rapidly (Steele, 1957) and this may have happened during a spell of xceptionally calm weather which immediately preceded the survey. In Fig. 8a the herring traces nearly ll lie within the 35·00‰ contour at 50m but Fig. 8b shows that a few days later they had spread very

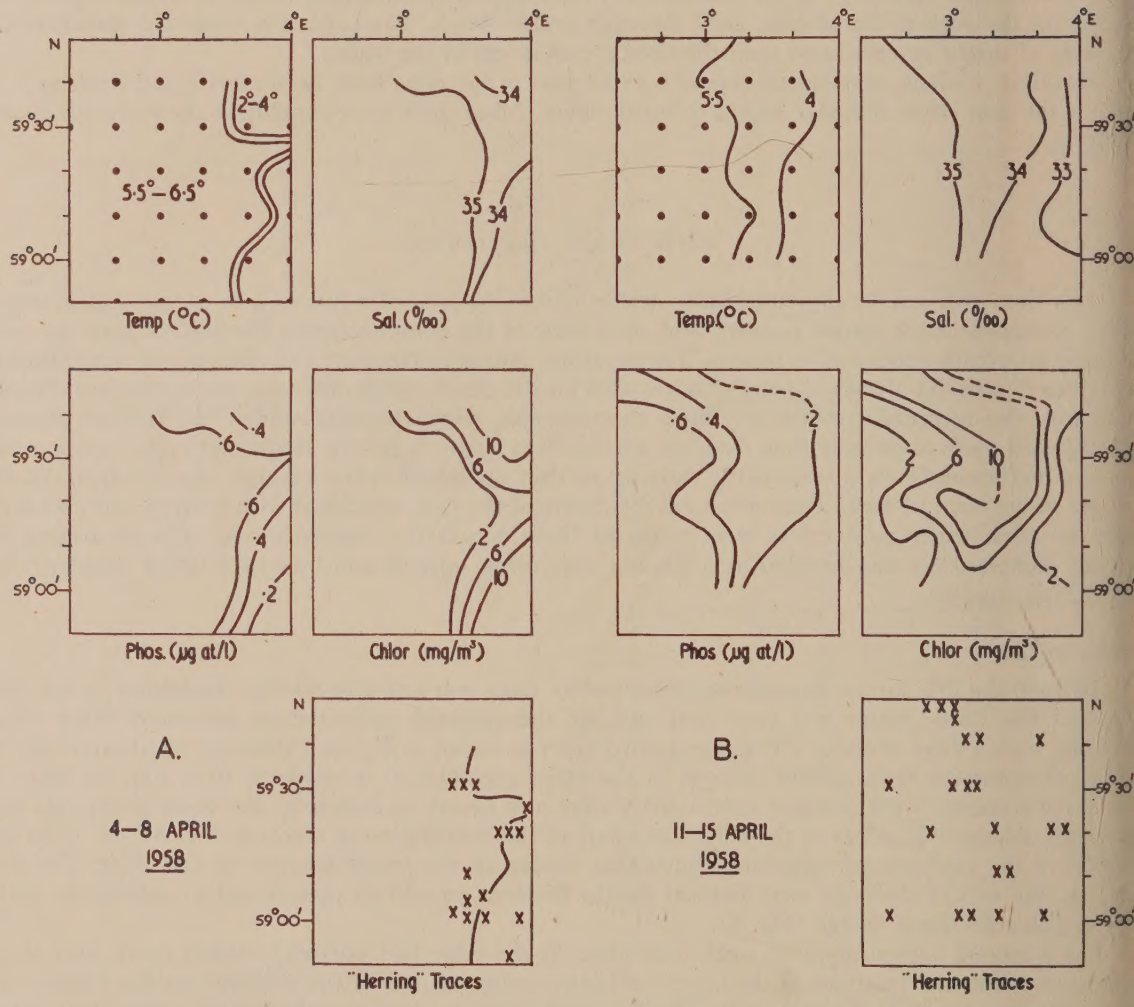

Fig. 6. Results of the two surveys in 1958 (except for herring traces, all data refer to 10m).

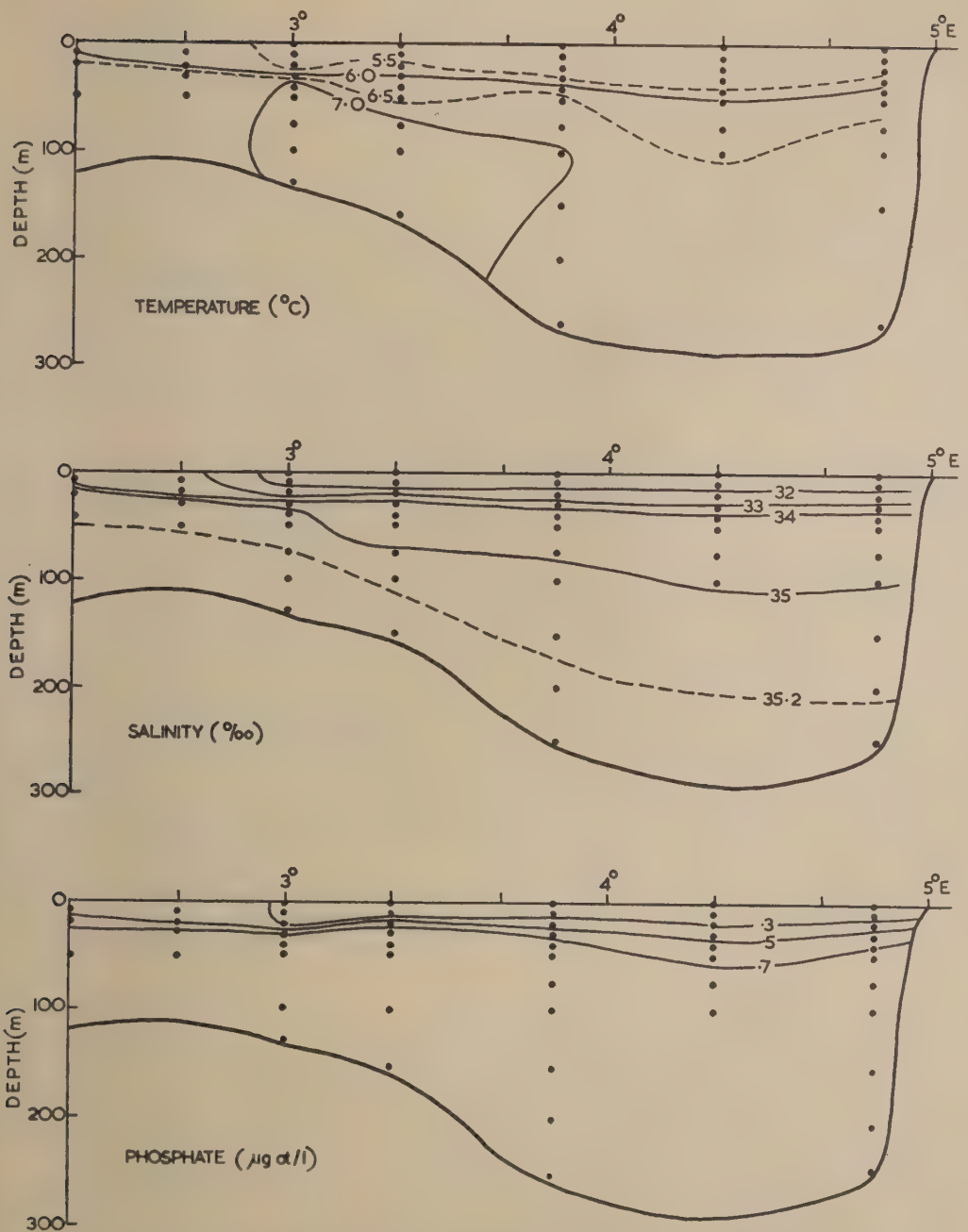

Fig. 7. Conditions on a section along 59°20'N during 13-18 April, 1957.

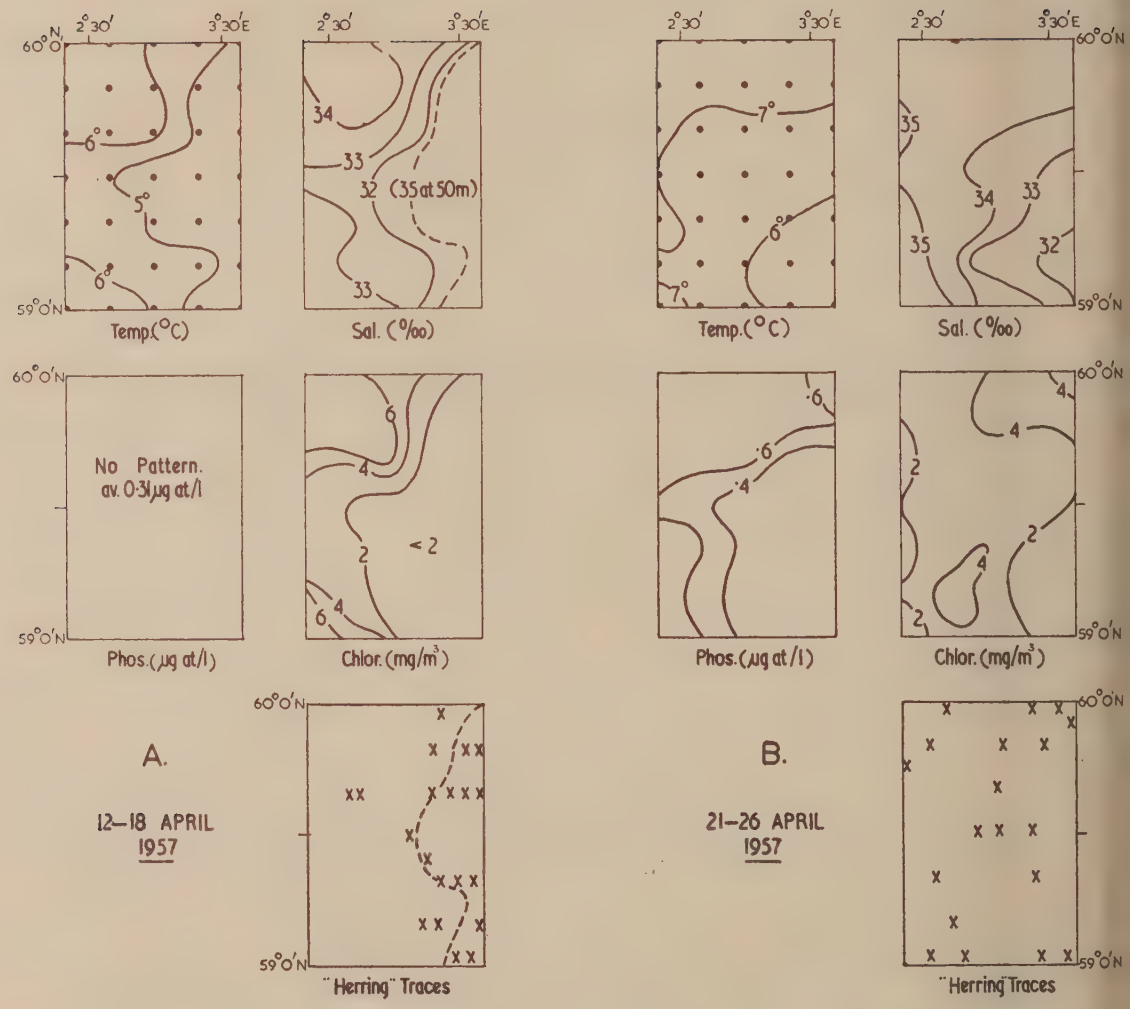

Fig. 8. Results of the two surveys in 1957.

kedly to the west. This suggests that there was a delay before the herring "responded" to the environ-
ital changes and moved into the area of mixing.

The high chlorophyll values to the west and low phosphate values over the whole area during the survey show that production had started in the thin layer whereas it was finished to the east. The eased salinity and phosphate and the lower chlorophyll values during the second survey were probably to the effects of vertical mixing by wind action which caused a deepening of the surface layer.

OPLANKTON IN 1957 AND 1958

The Hensen net gave rather poor samples at all stations, with copepods dominant. No sign of ificant patterns was observed in the distributions and in particular no changes occurred across the ge". The general average was about 3g dry weight m^2 or 15mg m^3. For the next two years a Gulf III npler was used to provide oblique hauls at high speed (5-6 knots). The method of collection at the of the net, a metal bucket with a mesh window, has since been found to give extremely small collections npared with a silk bag. Thus, unfortunately, the values given have no real significance and only the ative variations are important.

RIL, 1960

Once more, in 1960, the fresher water had begun to spread westwards near the surface, as shown by sections in Fig. 9. There was, again, the same marked increase in the depth of the layer at the eastern e. The position of this is shown by the contours of the depth of the 35‰ isohaline in Fig. 10. The hest chlorophyll values occur just to the east of this edge. Further, the surface thermograph showed mall but definite drop of approximately 1°C near the 6°C isotherm, close to the 50m contour of the 00‰ isohaline. The position of this thermal edge has been plotted on the chart of herring traces g. 10) and obviously provides a close agreement with the distribution of traces.

OPLANKTON IN 1960

The most striking feature of this survey was given by the zooplankton data. The euphausids, almost irely *Meganyctiphanes norvegica*, were separated from the rest of the collection, mainly copepods, and two parts dried and weighed. The copepod portion showed no significant changes over the area rresponding to the Hensen net hauls from 1957-58, but the euphausids were completely absent from western half. The dividing line was effectively coincident with the hydrographic boundary and with herring distribution. The variations in quantity of euphausids to the east seems to depend mainly on a y-night effect; the underlined values (Fig. 10), which are the night hauls, had an average five times at of the day hauls. The euphausids, unlike the herring, were not confined to the edge but were found all stations to the east of it.

HE YEAR 1959

The final year to be considered, 1959, was markedly aberrant. In the other years there were, effect-ely, only two water masses, the colder, fresher Baltic water overlying water with a temperature usually tween 6·0° and 7·5°C and a salinity between 35·00 and 35·30‰. In 1959 there was a strong and rapid utherly flow across the area studied. This water, with a temperature greater than 8°C and a salinity eater than 35·30‰, can be considered to be of recent "Atlantic" origin since it is similar in character the water found in winter in the Faroe-Shetland Channel (Tait, 1957). The water movement was so pid that the data have been split up into shorter intervals than usual as shown in Fig. 11.

The first survey (A) gave a normal "edge" indicated by the 35‰ isohaline, with all the observed aces lying near it; but in the north-west corner water with a temperature of 8°C was noted. Two days ter (B) it had begun to shift south and the traces which had lain in its path were no longer found. After is (C) the water pushed further south and at the same time under the original edge so that the con-nuous 8°C contour now indicated the surface edge and the broken contour its sub-surface spread. he spread was sufficiently strong to force its way through to the surface to the east of the northern line stations. (In both the charts C and D the positions of about 30 very close stations to the south are not

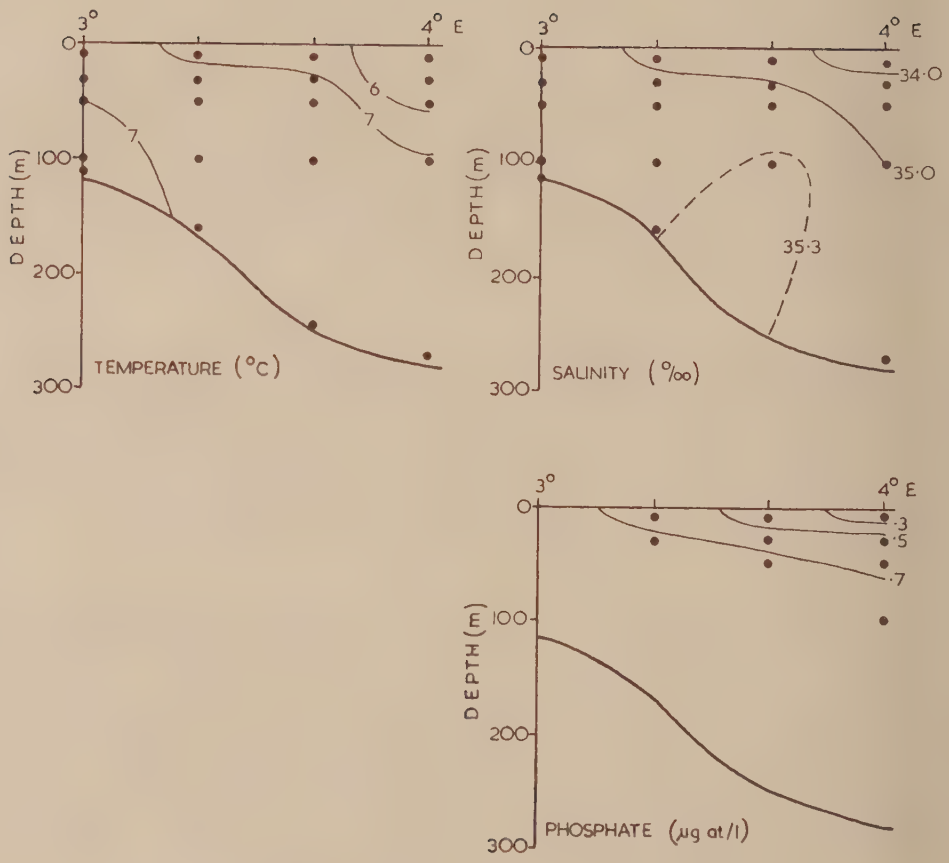

Fig. 9. Conditions on a section along 59°30′N in April, 1960.

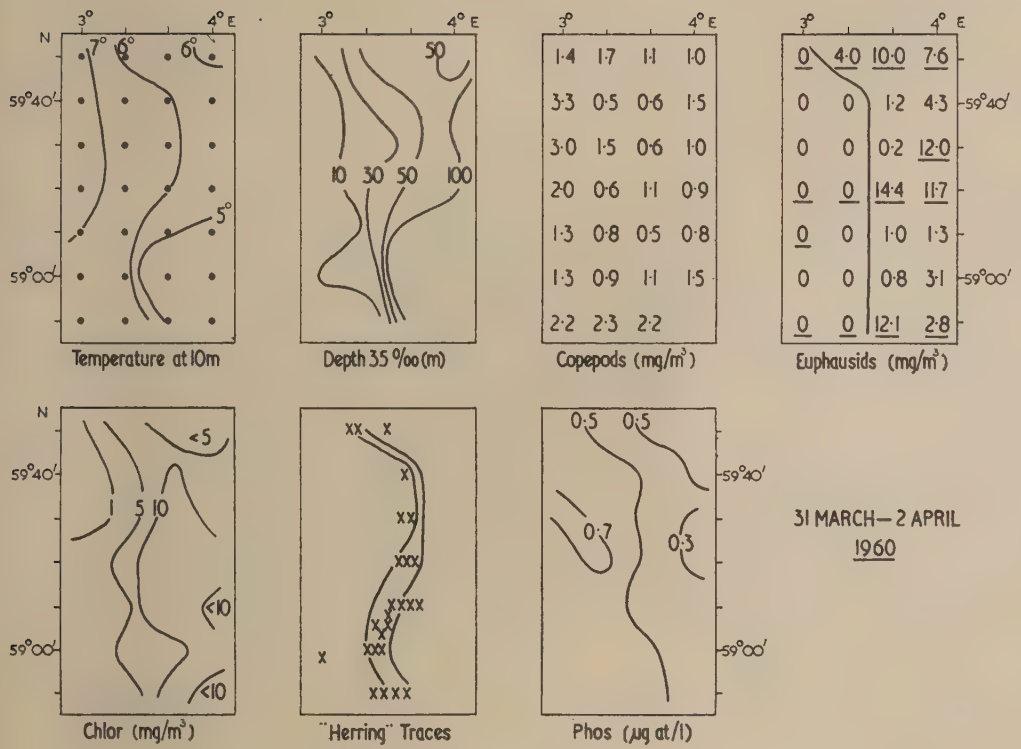

Fig. 10. Results of the survey in 1960.

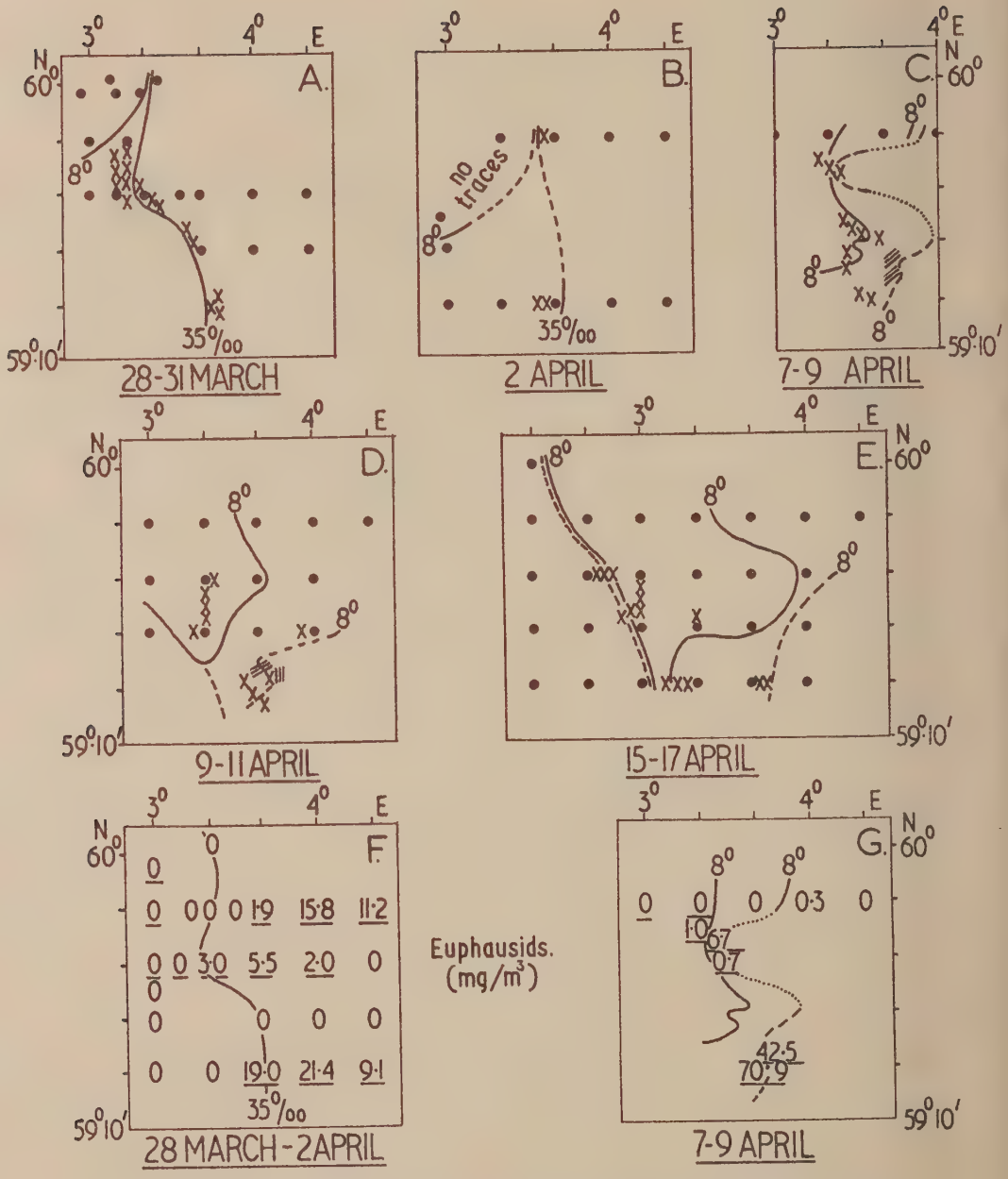

Fig. 11. Results of the surveys in 1959 split into short time intervals to show the effects of the intrusion of Atlantic water indicated by the 8°C boundaries (see text).

wn. The dotted parts of the contours indicate areas with no observations.) On chart D the spread to east occurs both at the surface and underneath the Baltic water, and extends still further in chart E ering a large part of the area. Some idea of the vertical changes is given by Fig. 12 which shows the ditions along latitude 59°50′N.

It is not possible to give a straightforward description of the probable relations between the fish ributions and these unusual events. Charts A and B imply that some of the fish were displaced to the th. In C and D many normal plume traces and also some dense continuous traces occur in the south-, but whereas most of the former were at the surface edge, the latter lay along the subsurface limit he 8° water. In chart E many of the traces are at the western edge. Although the distributions are not r there is the suggestion that the fish generally remained at either the surface or subsurface boundaries he inflow of warm saline Atlantic water.

OPLANKTON IN 1959

Sampling with the Gulf III was carried out until half way through the cruise when, unfortunately, sampler was lost. The first chart of euphausid distribution (Fig. 11f) shows the same important ure as the 1960 data—all the animals were found to the east of the edge and were, unlike the herring, erally distributed in this area. The day-night effect is more obvious this time, presumably because pling was to a fixed depth of 150m instead of to near bottom as in 1960, implying that during the the euphausids were close to the bottom. The second euphausid chart (Fig. 11g) has one interesting ure; the high values found in the south-east correspond to the occurrence of the dense continuous es described earlier.

The quantitative dominance of the euphausids would suggest that they are the main source of food the herring. Stomach samples collected by Rudakova (1959), on Viking Bank in February and March e composed entirely of euphausids. Six collections of stomach samples, each of 50 herring, were ained from English drifters during the 1959 cruise. In five of the samples euphausids were the dominant d; only one sample contained few euphausids and this was from a poor catch taken well to the west 59°50′N 3°02′E on 8th April. Thus, although more evidence is required, it seems reasonable to suppose t the herring were feeding very largely on euphausids.

DISCUSSION

DROGRAPHY

In general three "types" of water are present in the area. Indigenous North Sea water, with a perature of 6-7°C and a salinity near 35·20‰, predominates and this water shows the least vari-lity of the three. The Baltic water is always colder and less saline although it is characterised by ite large and apparently independent variations in its degrees of coldness and freshness. The temperature n be greater or less than 4°C, a feature which was suggested at the beginning as a possible limiting tor in herring distribution. The minimum observed salinities in any year have been from 31‰ to 33‰. e third water type comes from the southward movement of water down the western slope of the rwegian Deeps. There are signs of this in the years other than 1959, as shown by areas of slightly gher temperature and salinity, but these do not seem to exert any effect on the position of the Baltic ter. Only in 1959 had water of high salinity and temperature a strong effect on the pattern of the ier two masses. It is not possible to say how often this will occur.

IMARY PRODUCTIVITY

The outstanding feature of this area is the very high level often attained by the chlorophyll con-ntration. This can be explained in terms of the very shallow surface layer which is caused by the great bility. In these layers which are usually 10-20m thick the high average light permits large plant pulations to grow. The stability also inhibits the supply of nutrients by vertical mixing so that the tburst is short-lived. This outburst occurs progressively further west as the surface layer mixes gradually

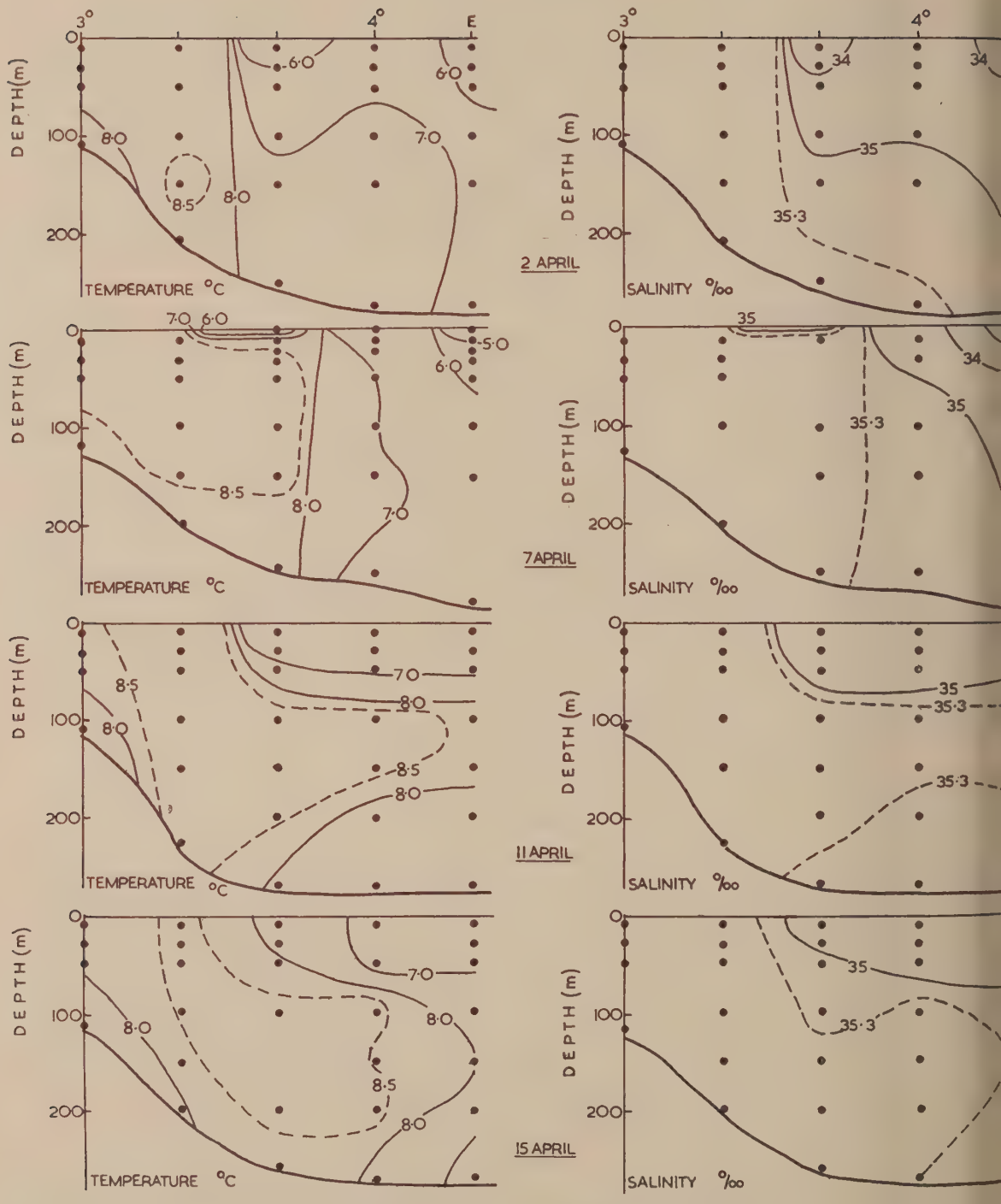

Fig. 12. The changes on a section along 59°50′N during 1959.

this direction. The relationship between phosphate and chlorophyll at 10m in 1960 (Fig. 13) shows t, as the phosphate decreased, the plants increased to their peak and then died out. This corresponds principle with the theoretically expected distributions (Steele, 1961).

OPLANKTON

On the basis of the original hypothesis, the changes in productivity should have resulted in a general rease in herbivorous zooplankton. The increase, however, was found, not in the copepod population, might have been expected, but in the euphausids, especially *Meganyctiphanes norvegica*. This species is inly carnivorous; it is known (Mauchline, 1959) to feed to some extent on dinoflagellates, but not to y significant extent on diatoms, which dominated the phytoplankton in the area studied here. Thus, here is any feeding relationship in the correspondence of water and euphausid distribution, it must a complex one in terms of predation on copepods. Further, from two horizontal hauls at night, in l below the surface layer of Baltic water (10m and 60m), the upper haul had only one twelfth the mber of *Meganyctiphanes* taken in the lower haul, although the copepods' weights were very similar. us it seems possible that the euphausids do not enter the cold water but migrate diurnally between ur-bottom and the foot of the Baltic outflow.

RRING

The distributions of typical echo-traces attributed to herring correspond to the main fishing areas ere vessels were densely concentrated. The fish caught in this area are a mixture of two "races", the umn-spawning stock already mentioned in the introduction and a stock of spring-spawning fish. The portions of the two stocks vary considerably, but over the years studied the spring-spawners con- uted about 20% to 40% of the whole (Parrish *et al*, 1959, 1960 and unpublished). Both stocks appear ake part in the westerly dispersal after mid-April but thereafter they separate (Parrish *et al*, 1960), hat the general migration pattern of the spring-spawners is different from that of the autumn-spawning outlined in the introduction. It is, perhaps, an indication of the strength and simplicity of the con- ling factors during March and April that the two stocks should appear to react in the same way to changes in the hydrographic "edge".

There remains a problem which is really outwith the scope of this study, namely, the means by ch herring could detect, and so react to, these gradients in the environment. The most extreme lateral dients observed in the surface layer were probably of the order of 0·5°C/km and 0·5‰ salinity/km. er the edge had broken down the gradients were roughly about one tenth of this, i.e. 0·05°C/km and 5‰/km.

In the experiments by Bull (1952) the minimal changes to which individual teleosts were found to ct were 0·03°C and 0·2‰. It is probable that, in terms of dimensions of the order of a single fish, the izontal gradients in the sea are much too small for the fish to react to them directionally. Pelagic fish, wever, generally swim in shoals whose diameter is several orders of magnitude greater than that of n individual. A typical "plume" trace of herring could represent a shoal of about 100m diameter. s generally assumed (Morrow, 1948) that "the formation of a school seems to depend upon the action which other fish exert upon the individual. Fish tend to remain parallel to and at a given ance from their fellows". If the fish at opposite edges of the shoal react slightly differently to an ironmental gradient, for example by moving more quickly or more slowly, then the whole shoal ld be regarded as a detection unit, as shown schematically in Fig. 14. In this way the reactions of vidual fish which could detect small differences in the environment without being able to determine direction of the more favourable environment, might enable the shoal as a unit to move towards urable conditions.

In such circumstances, the values given by Bull would permit the shoal to discriminate gradients of C and 2·0‰ per km. These are more nearly of the order of magnitude of the steepest gradients, but ould still require a finer discrimination in behaviour of herring for the shoals to react directionally to more normal very small gradients.

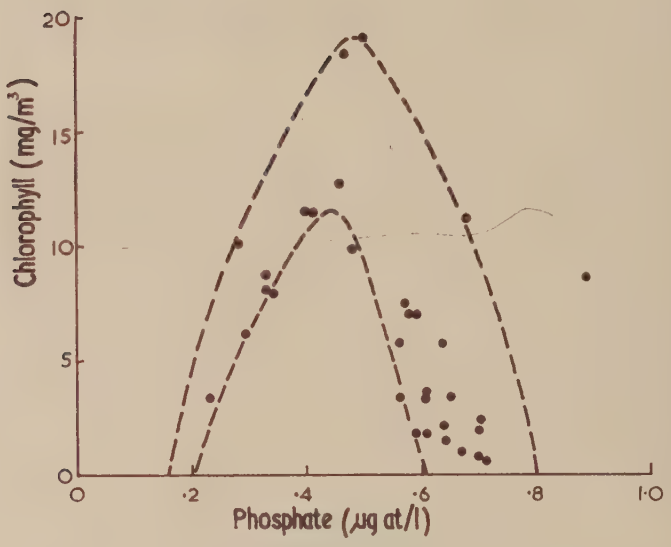

Fig. 13. The relation between chlorophyll and phosphate at 10m in 1960.

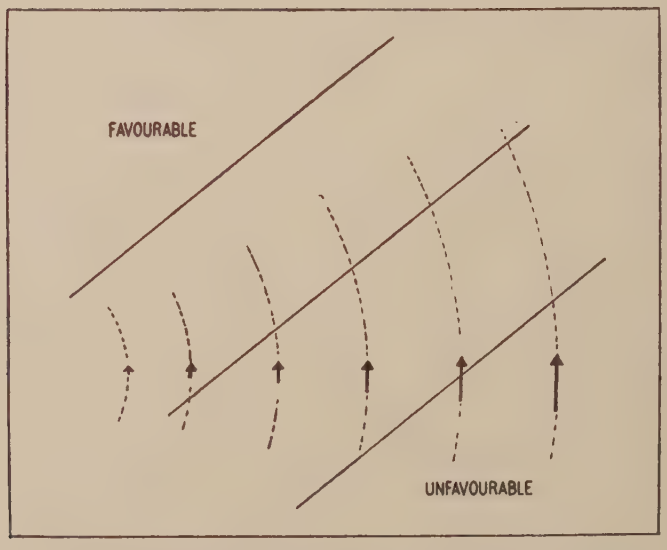

Fig. 14. Schematic description of the way in which differing reactions of individual fish could direct a shoal towards a favourable environment.

CONCLUSIONS

The original aim of this work was to test the idea that, at the edge of the Norwegian Deeps, the ence of very abrupt hydrographic changes and their ensuing diffusion might correspond to the ing concentrations in this area and the subsequent dispersal of the shoals to the west. This corres- dence has been shown to be very close, and the limiting factor in estimating the degree of corres- dence is possibly the closeness with which stations can be spaced in the available time. The herring ear to remain at the edge (defined as 35·00‰) of the "Baltic" type water and do not go far under- h the edge of the outflow. This vertical limit seems to be at about 50m and it may be that, when the om of the layer is deeper than this, the upper limit for vertical migration is too deep for the fish.

Very simple relationships were postulated to explain this correspondence in terms of the contrasting ts of food seeking and of avoidance of water the temperature of which is less than 4°C. The postulated ern in the primary productivity of the water has been demonstrated and also an increased zooplankton ulation under the productive area with the herring feeding on its western edge. But since this increased plankton is due to the presence of the carnivorous euphausid *Meganyctiphanes norvegica*, its distribution not be explained simply in terms of the increased plant productivity and might be caused by other nown factors. Similarly, the absence of the herring from the main body of the Baltic outflow cannot be ained in terms of a simple temperature reaction since the same effect occurs over a fairly wide range mperatures for the outflow. Thus the avoidance may be associated with general changes of temper- e, salinity and density occurring at the edge. It is intended to develop these studies in the hope of ing more detailed interpretations.

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